

bly dry or wet seasons are more likely to be followed by nearly normal seasons than by the complementary characteristics; so that here again, as with temperature, it is not true that a warm or a dry winter is followed by a cold or wet summer, or vice versa.

#### FRESHETS IN JAMES RIVER, VA.

The annual summary of the Virginia section contains an excellent article on the combinations of circumstances that bring about freshets in the James River. We copy the following table showing the principal freshets during the past thirty years. Concerning these cases, twenty-six in all, Mr. E. A. Evans says:

Fourteen, or 54 per cent, occurred during months when the absorption by the soil and the evaporation by the wind were at a minimum; five, or 19 per cent, when evaporation was greater, but absorption was retarded by the prior sodden condition of the ground; seven, or 26 per cent, occurred when both evaporation and absorption were at a maximum, but when the rate of rainfall was greater.

*Maximum river gage readings showing height above low water during important freshets in the James River, Va.*

Date.	Lynchburg.	Scottsville.	Columbia.	Richmond.*	Ratio of Columbia to Richmond.
	Feet.	Feet.	Feet.	Feet.	Per ct.
October, 1870.....	14.4	23.8	39.0	27.0	69.3
November, 1877.....	11.8	26.3	37.5	26.6	76.3
March, 1884.....	9.8	14.0	20.0	13.7	68.5
March, 1884.....	12.2	17.4	24.0	15.7	65.4
October, 1885.....	13.0	16.2	30.5	15.9	52.1
November, 1885.....	.....	.....	30.5	14.2	46.4
January, 1885.....	.....	17.0	24.0	14.7	61.1
April, 1886.....	10.8	22.5	32.0	24.3	75.9
July, 1886.....	.....	.....	23.8	17.2	72.3
August, 1889.....	.....	.....	29.5	22.5	76.3
June, 1889.....	.....	.....	32.5	25.2	77.5
April, 1891.....	.....	.....	20.5	14.4	70.2
January, 1892.....	.....	.....	20.3	13.5	66.5
May, 1893.....	13.9	17.8	27.0	16.9	62.6
January, 1895.....	10.5	18.4	28.8	18.2	64.2
March, 1895.....	.....	.....	20.0	12.7	63.5
April, 1895.....	15.3	19.2	26.0	16.4	63.0
July, 1896.....	10.2	14.2	19.3	12.5	64.9
October, 1896.....	15.7	.....	28.5	16.7	58.6
February, 1897.....	.....	.....	21.7	11.9	55.3
February, 1897.....	.....	17.5	26.2	15.0	57.3
October, 1898.....	12.0†	.....	.....	11.7	.....
January, 1899.....	8.6†	.....	.....	13.5	.....
February, 1899.....	5.6†	.....	.....	22.0	.....
March, 1899.....	19.0†	.....	.....	20.5	.....
March, 1899.....	7.7†	.....	.....	13.6	.....

\*Readings taken from United States James River improvement gage until 1897, when they were taken from Bureau gage. †On Bureau gage.

#### PHENOLOGY IN OHIO.

In the annual summary of the Ohio section Mr. J. Warren Smith, Section Director, discusses the question of the relation of temperature to the date of harvesting wheat. The harvest data for twelve consecutive seasons at Wooster, Ohio, and for forty-four consecutive years at Osborn, Ohio, are compared with the mean temperatures and total rainfall of April, May, and June at the same or neighboring stations. In general, Mr. Smith finds that the dates and the temperatures fluctuate together, the dates being earlier in proportion as the mean temperature of the three months is above the normal and late when the temperature is below the normal. On the contrary, the precipitation varies inversely as the date; a deficit in rain causes an earlier harvest. Thus in 1899 the date of harvesting was the earliest on record, coinciding with the greatest recorded deficiency in rainfall.

As this study relates to winter wheat, we may remark that it has been customary for European students usually to calculate the sum total of the effective temperatures from the

date of sprouting, and it is likely that such calculations would have made some appreciable differences in the Ohio temperatures. With regard to precipitation, we are inclined to think that the acceleration of the date of harvest by droughts and clear weather, or its retardation by rain and cloudy weather is mostly effected during the three months, April, May, and June, tabulated by Mr. Smith. However, we think that the total temperature or rainfall for the month of June ought scarcely to be considered in studying those years in which the wheat ripens as early as June 20.

As the dates of harvesting winter wheat may be needed by others in climatological studies we reprint the figures given by Mr. Smith. On the average, the Wooster date is 6.6 days later than the Osborn date:

#### Dates of harvesting wheat.

Year.	Osborn, Ohio.	Wooster, Ohio.	Year.	Osborn, Ohio.	Wooster, Ohio.
1856.....	June 28	.....	1878.....	June 25	.....
1857.....	July 16	.....	1879.....	June 27	.....
1858.....	July 1	.....	1880.....	June 21	.....
1859.....	June 28	.....	1881.....	.....	.....
1860.....	June 25	.....	1882.....	July 4	.....
1861.....	July 1	.....	1883.....	July 6	.....
1862.....	June 30	.....	1884.....	July 3	.....
1863.....	June 30	.....	1885.....	July 9	.....
1864.....	July 1	.....	1886.....	June 28	.....
1865.....	June 29	.....	1887.....	June 23	.....
1866.....	July 6	.....	1888.....	July 4	July 8
1867.....	July 1	.....	1889.....	June 29	July 3
1868.....	July 6	.....	1890.....	June 27	July 3
1869.....	July 5	.....	1891.....	June 27	July 1
1870.....	June 25	.....	1892.....	June 29	July 2
1871.....	June 26	.....	1893.....	July 3	July 8
1872.....	July 4	.....	1894.....	June 28	July 8
1873.....	July 1	.....	1895.....	June 25	July 6
1874.....	June 26	.....	1896.....	June 22	July 3
1875.....	July 12	.....	1897.....	July 2	July 7
1876.....	July 1	.....	1898.....	June 23	July 2
1877.....	June 29	.....	1899.....	June 20	June 27

#### HAIL AND ITS METHODS OF FORMATION.

In the March report of the Virginia section Mr. E. A. Evans, Section Director, gives some interesting items with regard to the unusual features of the snowstorm of March 25, 1900:

The morning of this date was cloudy, with a fresh, chilling, north-east wind. The temperature rose slowly during the forenoon, and at 1:17 p. m. a light rain began to fall. Soon sleet accompanied the rain, and later the rain ceased and sleet alone fell. Some of these icy particles were nearly cubiform, measuring perhaps one-fourth of an inch either way. Mixed with these was the sleet ordinarily seen—the small spheres of frozen rain. At 5:25 p. m. moist snow fell with sleet. At first the flakes were not large enough to be specially noticeable, but as the fall of sleet diminished in volume, which it immediately did, the size of the flakes increased until they attained unusually large proportions. They were of irregular shape, mostly oblong; several were seen the greatest diameter of which could hardly be covered by a teacup. Some were caught upon a piece of dry wood and examined. In every instance the center of the flake was composed of a soft mass of snow about half an inch in diameter, while the outer edges were thin, looking as though they might have been separate flakes which had attached themselves to the central mass while it was falling. The weight of the center being greater than that of the edges caused the larger ones to assume the form of an inverted cone in falling, the outer edges being bent up by the resistance of the air.

Three of the large flakes were caught in a bowl, yielding, when melted, nearly a tablespoonful of water. There was nothing at hand from which an absolute measurement could be had, but it is estimated that it would have closely approximated one one-hundredth of an inch. The flakes were widely separated from one another and did not obscure the vision in looking upward toward the sky.

The above interesting description reminds one of the natural snowballs described by the observers on Pikes Peak during the early years of the occupation of that station. These balls are said to have been 2 or 3 inches in diameter, and it was supposed that by melting and recongealing as they fell they formed icy hail with snowy nuclei. In the present case the lenticular snowflakes are said to have had a denser mass of

snow at the center, while the outer rims seemed to have been composed of separate plates, attaching themselves to the central mass as it fell. By some such process as this the remarkable hailstones that figured in the MONTHLY WEATHER REVIEW for April, 1877, might have been formed.

There are many reasons for believing that hailstones are formed in the free atmosphere by some one of several different processes, each of which may be in accord with the laws of thermodynamics:

1. An ascending mass of air may be so dry that it does not cool to the dew-point until far below the freezing temperature, in which case the deposit is either fine spiculæ of ice or aggregations of these into small snowflakes.

2. If the dew-point is a little higher than the preceding, the cloudy condensation may occur at temperatures just above the freezing point and the watery particles may be carried up a little higher and frozen into what is called frozen fog. These same particles, when driven by the wind against an object, accumulate on it as frostwork.

3. When a rising mass of air forms a large cumulus cloud at a low level, having a rapidly ascending current in its interior, the latter, by its buoyancy, will rise much higher than if there were no cumulus cloud; it may pass upward into the so-called hail region, where water drops and ice particles may coexist, and still higher up into the region where only ice and snow can exist.

4. Raindrops falling from relatively warm clouds through a very cold stratum of air below may be frozen into sleet before they reach the ground.

To these four elementary methods of forming atmospheric ice we have to add the mechanical processes by which the small particles accumulate as large hailstones. Undoubtedly much light was thrown upon this subject by the notes made by our observers on Pikes Peak, some of which are quoted, as follows, beginning with those by Mr. Robert Seyboth, as quoted in the MONTHLY WEATHER REVIEW for June, 1874:

The observer on the summit of Pikes Peak states that the local storms there experienced come from the northwest, west, or southwest, and evidently originate over the central portions of the parks on hot afternoons. One such storm approached his station under conditions very favorable for observation, and he noted that while the cloud-bearing currents of air flowed toward the rotating center from all directions, they also had a decided downward movement, but that through the interior, funnel-shaped masses of smokelike vapor rapidly ascended.

1874, July 1, a heavy thunderstorm passed over the summit from southwest to northeast, between noon and 2 p. m., and sleet of remarkable size fell during its progress. The stones were of hard snow without nucleus, and many of them as large as pigeon eggs; violent cloud whirls were observed before the beginning of the sleet, the wind backing to the southeast, with falling temperature.

1874, July 21, heavy hail began at 2.05 p. m., some of the stones varying in size, and composed mostly of solid transparent ice. The hail came down in continuous torrents until 7.30 p. m., when it was succeeded by light rain; the lightning was terrific and simultaneous with the thunder. The storm did not extend much beyond the Peak.

1875, May 29, hail from 11.30 a. m. to 1.40 p. m., accompanied by electricity. The observer notes that in all hailstorms the fall of hail entirely ceases for about half a minute following a heavy electric discharge, and that the hailfall is considerably heavier for some little time following the discharge than before. Some of the stones collected were as large as peas, almost round, and formed of hardened snow. The observer failed to discover the whirling motion in front of the cloud, as described by Professor Loomis.

1875, August 10, from 3 p. m. to 8 p. m., occurred the heaviest hailstorm the observer ever saw. The stones averaged an inch in diameter, while those fully two inches in diameter were not rare. On being broken they presented a stratified structure with a center of clear ice, the outer covering being of soft snow. The electricity was not so strong as during some minor storms.

1876, April 23, hail began at 9.45 a. m., and continued until 2.30 p. m.; falling very heavily at times and accumulating on the crest of the snow to the depth of an inch. The stones were not solid ice but hardened snow, without any appearance of nucleus, and of all sizes up to that of a pea.

1876, June 15, 7.30 p. m., a hailstorm began which continued with great fury for 20 minutes, and at intervals afterwards. At first the

stones were quite small, not larger than peas, but after a few moments they were of greatly increased size, many of them being at least an inch in diameter. They had a decided nucleus around which were plain concentric formations. The nucleus uniformly consisted of hard white ice, while the concentric rings were of transparent ice, either solid or spongy, except the outer one, which was of snow. As the stones fell on the tin roofs over our heads they made a deafening noise; thunder and lightning accompanied the storm in very liberal amount.

1876, August 6, hail began at 1:55 p. m., but soon turned to snow, which fell in very large flakes.

1877, October 12, at 11 a. m., a heavy cloud came over from the west and enveloped the Peak; violent thunder followed. At noon the summit was in the midst of a very heavy thunderstorm, which passed to the plains at 1 p. m., affording an excellent observation on the formation of hail. The rotary movement of the hail cloud could plainly be seen and with every violent flash of lightning the passing cloud would grow perceptibly darker, indicating increased condensation. The hail formed by this cloud must have fallen about three miles below, for the wood packers reported white solid hail at timberline and none above. This verifies the theory that a hail cloud can be transported laterally several miles while the ice stones are forming.

1878, May 8, sleet commenced at 4 p. m. and continued into the night. The progress of this storm was observed with great interest with reference to the origin of rain. It would seem from this sleet that Hutton's theory of rain is not based on mountain observations and the observer is now led to believe that the origin of our summer rains is the same as that of hail, and that two masses of air never come together or collide in such a manner as to produce direct and copious precipitation. It is believed that every raindrop has its origin in a compact ball of snow which melts in descending through warm air.

1878, May, 11, heavy hail. \* \* \* Each hailstone consisted only of compact snow, which when melted made but a drop of water.

1878, June 10, heavy hailstorm. \* \* \* Balls of compact snow fell fully half an inch in diameter.

1878, June 29, during the afternoon a most wonderful storm was witnessed in South Park, about 50 miles away. Small fragmentary clouds coming from the snowy range assembled rapidly in dark masses which assumed the shape of an inverted cone. The cone once formed, small clouds could be seen drifting rapidly in all directions from the center. At 4 p. m., the inverted cone, having been nearly stationary for about forty minutes, suddenly began to rise like an immense balloon and upon attaining considerable height, gradually lost its form and soon after dissipated. A white spot of 10 or 15 acres showed that this had been a tremendous hail waterspout; the hail did not disappear until nearly sunset.

1879, April 26, at 2:45 p. m., a severe storm came from the northwest, with heavy thunder. During the continuance of this, from 3:07 to 3:20 p. m., 2 inches of sleet and hail fell, ranging from one-eighth to one-half inch in diameter. Every piece examined was in the shape of two cones, joined at their bases, with streaks from the center to each cone, and looked as though they had been under heavy pressure and had popped out, or the pressure had slid off, forcing them together at the base. There was no ice in their composition though they were hard; they could be crushed between the thumb and finger, when they would crumble into fine snow, and before they were mashed they were as white as snow. During this heavy fall of sleet loud peals of thunder followed one another in quick succession. The wind was very changeable between north and west, showing decidedly more than one current, as it changed suddenly from north to west and reverse.

1879, May 14, snow began at 1:40 p. m.; ended at 2:30 p. m. The first that fell was a round solid mass, the form of hail and about the size of buckshot. It was not frozen and could be easily crushed in the hand. Shortly after it changed to light snow.

1879, July 10, a severe hailstorm began at 2:15 p. m., accompanied by terrific thunder and intense lightning. At 5 p. m. the hail turned to snow and ceased at 5:30 p. m. The wind was gentle throughout.

1879, July 15, one of the most severe hailstorms began at 3:27 p. m., most vivid lightning; the hail was the size of bullets; the storm ended at 5:15 p. m.

1880, June 18, at 2:30 p. m., light snow fell from a small thunder cloud over the Peak until 3:15 p. m.

1880, July 23, at 11 a. m., the Peak began to be enveloped in a dense mass of clouds and a heavy fog, and at 12:30 p. m., a hailstorm set in. Intense ground currents of electricity quite frequent.

1880, August 3, hail with terrific lightning; at 12:50 p. m. the hail changed to snow and the lightning diminished.

1880, October 26, at 12:50 p. m., a heavy thunderstorm from the north, with light snow and heavy sleet at intervals.

1881, June 2, hail and light snow at intervals from 1:35 until 6:45 p. m. The hail was accompanied by terrific lightning.

1881, July 2, 11:45 a. m., a heavy fall of hail with terrific lightning continued until 12:30 p. m.

1881, July 4, hail at 11:10 a. m., and continued at intervals until 11:40 a. m., when it turned into light snow and so continued until 4:54 p. m., when it turned into a heavy rain, which continued falling until the midnight observation (9:07 p. m., local time).

1882, June 7, the summit was densely enveloped, and a heavy sleet began at 3:45 p. m., continuing at intervals until 8 p. m., when the wind, previously calm, suddenly began from the south at 20 miles per hour, and the sleet changed into heavy dense snow with a flash of lightning from the north. During the fall of sleet the peculiar singing or sizzling noise was heard on the wire. From 8:45 to 8:55 interesting electrical phenomena were observed, accompanied by dense driving snow, all of which then ceased suddenly.

1882, July 12, a thunderstorm, with hail and sleet. At 4 p. m., during the heaviest hailstorm, and when the wind died down to a calm, the observer went out to examine it as it fell on the roof in a deafening storm. The largest of the hailstones were an inch in diameter, of a balloon shape, not round and much harder than any ever seen by the observer, requiring a heavy blow with a rock to crack them.

1883, June 24, sleet and hail fell from 1 p. m. to 2:30 p. m. Some of the larger hail was fully one and a quarter inches in diameter and was very peculiar both in shape and composition. There were no icy layers or rings of ice, but the whole body of the stones was of a light porous nature. In shape they resembled a balloon, the smaller end coming nearer to a point. The smaller stones were nearly perfect spheres.

1885, August 29, thunderstorm from the northeast moving southward from 5:45 p. m. to 6:12 p. m., accompanied by sleet and hail. Hailstones, spherical, of opaque snow formation, four-tenths of an inch in diameter; during fall of hail the atmosphere was highly electrified; the usual buzzing noise, resembling that of bees, came from all pointed objects, as during every electrical storm in its passage over the Peak.

In the thermodynamic studies of Hertz and von Bezold is employed the expression "the hail stage," viz, that stage in which the temperature of  $32^{\circ}$  prevails in an ascending mass of moist air. It is supposed that the ascending air, having already cooled to the dew-point, is carrying up with it a quantity of water, either in small cloud particles or in large raindrops. When these have ascended to the level where the rising moist air is cooled to the temperature of freezing, they continue to give up to the air a little of their specific heat until they are themselves frozen into hail or sleet. There is, therefore, a thin layer of air in which this process of freezing is going on and where the rising mass of mixed air and rain is kept at a uniform temperature until all the water is converted into ice. This is spoken of by Hertz as the hail stage; below it is the rain stage and above it is the snow stage. In this latter region the ascending air, being already cooled below the freezing point, can deposit its moisture only as snow or small crystals of ice. Now, the actual hailstones observed on Pikes Peak are so frequently composed of snow that has been partly melted and refrozen, or mixed with water drops and refrozen, that we can not suppose them to have been wholly formed within the thin layer known as the Hertzian hail stage. It is more likely that they are formed partly within that and partly within the Hertzian snow stage. The memoir of Hertz assumes throughout that the changes of temperature within the ascending air are strictly adiabatic. This requires that the ascent be so slow that the drops of water carried upward maintain the same temperature as the surrounding air. But these two conditions are almost physically incompatible; it is probable that neither of them are ever realized in nature. Among other combinations that are possible and may help to explain the great variety of forms of hailstones that are caught upon the summit of Pikes Peak, we may suggest the two following as the most common:

1. Frozen raindrops carried very rapidly upward through the Hertzian hail stage may continue on into the snow stage and grow by the accretion of snowflakes until they are finally dropped to the earth, in which latter process they continue increasing their snowy covering. If, however, they pass through the hail stage before they reach the ground in their fall, they will be found to consist of an icy nucleus surrounded by a snowy envelope and covered over all by a layer of a frozen mixture of ice and snow.

2. Air that has ascended into the snowy stage without going through the rain or hail stage, or, at least, to a very slight extent, because of its dryness, may form large snowballs high above the Peak before beginning to fall. As such balls descend very rapidly, the interior retains a low temperature,

while the exterior is slightly warmed and melted by the action of the warmer air that the snowballs find near the ground. The result is large hailstones, consisting each of a thin layer or crust of ice and a snowy mass within.

3. In the formation of snow and hail in the midst of ascending currents of air, we must expect to notice the same phenomenon as in the formation of rain, viz, after the first condensations have taken place upon dust and foreign substances the rising mass of cloud represents dustless air in the presence of water particles, but cooled by expansion to such an extent that the air between the drops, or the ice spicules, is in a state of supersaturation. When this condition has become too intense, large quantities of aqueous vapor suddenly condense, rushing together into large drops of rain or large masses of snow, and carrying with them all the finer particles within their respective spheres. At the very low temperatures at which this occurs, water will hold considerable air in solution, and additional air is also included at the center of the snowball among the particles of snow and ice. Such large snowballs are heavy enough to descend rapidly from the snowy stage, through the rain and hail stages to the ground, and in so doing they become saturated with water which recrystallizes forming solid hailstones, but at the center of the mass they still hold, confined, the air originally included in the snowball, and this is compressed under several atmospheres, as was shown in 1869, by P. Reinsch (see Pogg. Ann., 1871, or L. E. D. Phil. Mag. 1871, Vol. XLII., page 79), who observed that when such hailstones are melted under water the little bubble of air at the center is seen to suddenly escape and expand sufficiently to demonstrate the existence of a pressure of 50 atmospheres under which it was confined. In this formation of snowballs and the resulting hail from supersaturated air within the snow stage there is an electric disturbance entirely analogous to that which takes place when great drops of rain are formed within the rain stage. In both cases violent thunder and lightning are observed just before the fall of the hail or the rain.

These and other hypotheses that might be framed relative to the methods of formation of the various kinds of hailstones must, however, only be regarded as suggestions intended to stimulate experimental and theoretical research in this direction. One can not doubt but that the history of the formation of hail is written in its structure if we could but interpret it.

#### STUDIES IN RAINDROPS.

In Popular Science for May, 1900, Mr. W. A. Bentley gives the results of some studies by himself on raindrops.

He catches the drops on a tray full of ordinary flour and finds that the pellet of dough formed at the bottom of each impression is very nearly the actual size of the original raindrop, which vary in diameter from one-fiftieth of an inch to one-fourth of an inch. He finds that the small raindrops are most commonly formed in the lower nimbus or upper cirro-stratus clouds when the intermediate cloud strata are totally absent, or nearly so. Small drops usually form the greater part of the rainfall on the outer edges of the showers and rainstorms, and a large part of the rainfall in all great storms. As a rule the size of the drops progressively increases as we pass from the outer edges to the central portions of showers and rainstorms. The larger drops originate in the upper and intermediate cloud strata, and a vast vertical depth of these clouds is usually necessary to their formation; they frequently come thence with no low clouds present below. The largest drops of all descend from newly formed or forming thundershowers, when cumulus clouds are expanding upward into the cirro-stratus crest that soon forms above and overhangs such showers. Newly formed or forming portions of older showers, and certain circumscribed central portions within the great rain storms, also shed large drops, but rarely are they so large as are those of thundershowers.

The drops of newly formed showers are often large to the extreme edge of the shower, and the rainfall portions of such showers often consist of large and medium drops alone, without small drops intermixed with them. Sometimes large drops fall scatteringly and alone, but more frequently they are associated with both medium and small